Information Sciences & Technology
Ames Research Center

Computational Sciences Division

Increased Flexibility and Robustness of Mars Rovers

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Objective: Improve rover productivity

Introduction

- Traditional commanding
  - Rigid, time-stamped sequences of primitive operations
- Proposed approach
  - Command with high-level, flexible, contingent language
- Enable planetary rovers to:
  - Handle uncertainty; e.g., action duration & resource use
  - Recover from operation failures
  - Take advantage of science opportunities

1999 Rover Field Test

- Used Marsokhod rover
- Simulated main objectives of Mars ‘01–’05 missions
- Conducted at Silver Lake dry lake bed in California’s Mojave desert
- Collaboration between Ames’ Computational Sciences and Space Sciences divisions
- Around 70 participants

Talk Outline

- Proposed commanding language
- On-board executive architecture
- Ground-based support tools
- Field test experience
- Concluding remarks

Contingent Rover Language (*CRL*)

- Example

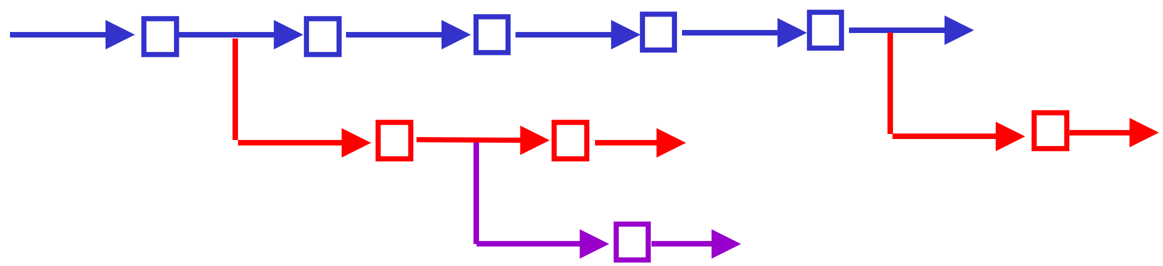
> Visual-servo to rock
>
> If success, then acquire NIR spectrometer reading
>
> Analyze spectrometer data on-board
>
> If carbonate detected, then acquire color stereo images
>
> If failure, then acquire image mosaic to help relocate

- Design criteria
  - Contingency and flexibility
  - Simplicity and compatibility

➡ branching & nesting, but no looping

Contingency in CRL

- Command plan
  - Nominal plan plus branches with ≥1 plan options
  - *Tree of alternative courses of action*

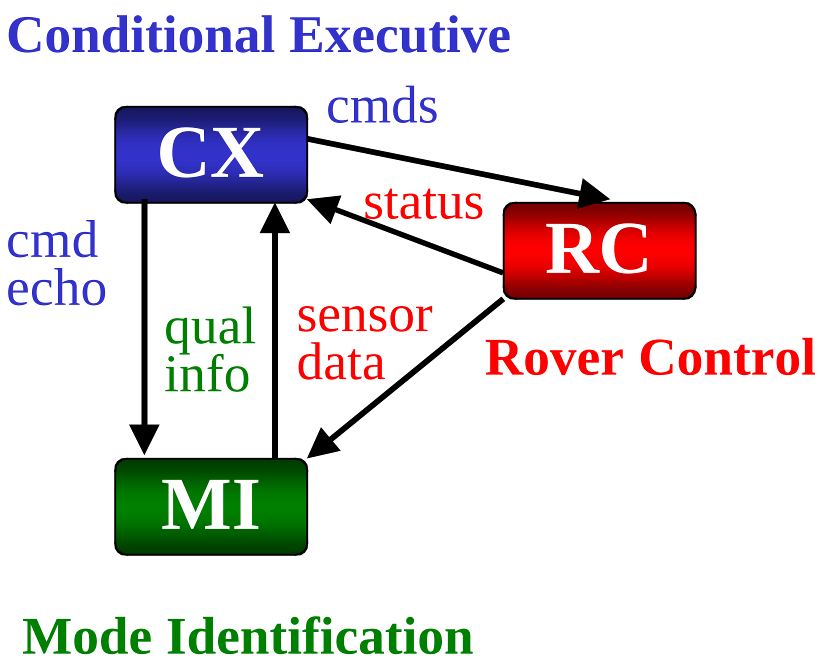


- Alternate plan library
  - Contingent plans not fixed to a point in command plan
  - ***Example***: Sojourner's *Backup Mission Load* and *Contingency Mission Load* for communication failures

Flexibility in CRL

- Condition categories
  - ***Start:*** Must be true before executing plan step
  - ***Wait-for:*** Start subset that will be waited for satisfaction
  - ***Maintain:*** If violated, execution is interrupted
  - ***End:*** Must be true after executing plan step
- Condition content
  - Temporal: *e.g., start window, max duration limit*
  - Internal rover state: *e.g., chassis pose limits*
  - External state: *e.g., carbonate detected in rock*
- Failure handling: ***continue*** to next plan step or ***abort***

Conditional Plan Execution

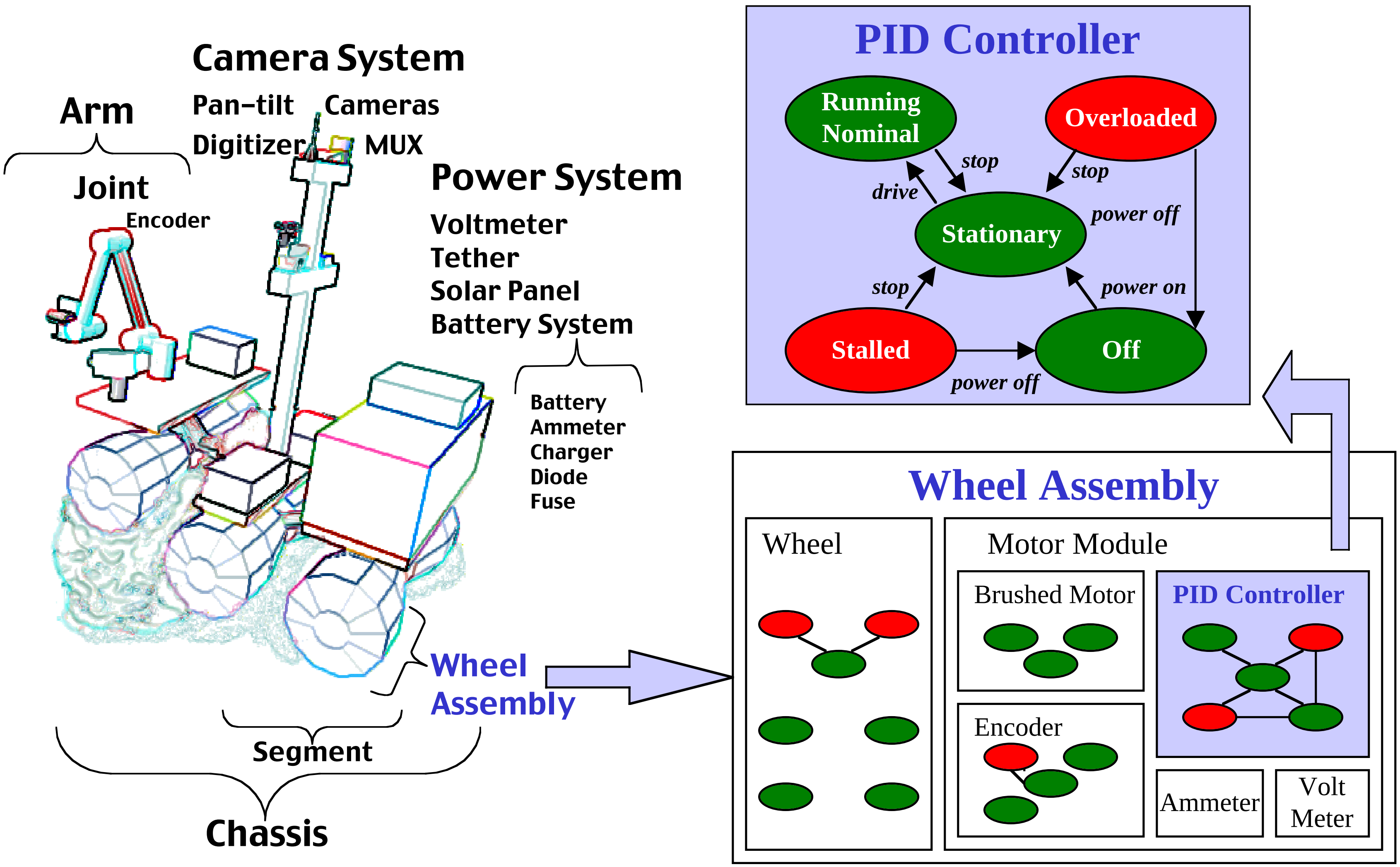


- **CX** executes uplinked command plan
- Sends cmd to **RC** and receives back cmd status
- Monitors conditions based on info from **MI**
- Selects contingency plan when warranted
- Handle plan failures

Mode Identification

- Task: State assessment and fault detection
- Approach: Qualitative, model-based
  - Continuous sensor → Monitor → {low, ok, high}
  - *Inputs*: Monitor changes, command issued, rover model
  - *Output*: Most likely state of rover system
- Advantages
  - Models are abstract, qualitative, and modular
  - Easier to acquire, verify, and re-use
  - Inference process is robust and efficient

Marsokhod Models



Command Plan Generation

- User interface tools
  - Photo-realistic 3D modeling
  - VR display and manipulation of models
  - Form-based goal and plan editing
- Contingent Planner/Scheduler (*CPS*)
  - Mixed-initiative command plan generation
  - Recursive decomposition of high-level tasks
  - ***Just-In-Case*** contingent planning approach

1. Generate nominal plan
2. Identify most likely failure
3. Generate a contingency branch
4. Integrate the branch into plan

Field Test: Plan Execution

- Results achieved
  - 1st Ames field test commanded via uplinked plans
  - Scientists appreciated advantages of contingencies
  - Supported on-board science analyses (GSOM)
- Lessons learned
  - To reduce uplink time, perform decomposition on board
  - Need to handle system failures too
- Future work
  - Integrate resource manager into on-board executive
  - Extend CRL to represent concurrent activities

Field Test: Mode Identification

- Results achieved
  - Modeled drive sys., power sys., camera sys., & arm sys.
  - Models useful for diagnosing some faults: *e.g.*, *wheels*
- Lessons learned
  - Some aspects are quantitative: *motor behavior*, *kinematics*
  - Need for conditional probabilities on state transitions
  - Violated assumption: *steady state with rapid transitions*
- Future work
  - Hybrid qual/quant (hcc) and MDP representations
  - Active sensing and learning approaches

Field Test: Plan Generation

- Results achieved
  - User interface tools were invaluable to operations team
  - Decomposition facility was essential for quick turnaround
- Lessons learned
  - CPS full capabilities were not utilized: *scientists kept constraints implicit and left no scheduling flexibility*
  - More suited for multi-day planning w/ large set of tasks
- Future work
  - Improve handling of resources and operation failures
  - Employ simulation facility for generation & verification

Concluding Remarks

- Overall objective: ***Improve rover productivity via increased robustness & flexibility of rover autonomy***
- Incremental technology strategy
  - 1st improve ground capabilities
  - Migrate capabilities on-board as appropriate
- Initial focus: "**contingency**" & improved commanding
- Next steps
  - Incorporate resource manager into executive
  - Improve state assessment component
  - Integrate simulation facility in ground tools

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